

Environmental Impact of Heavy Metals from Poultry Waste Discharged into the Olosuru Stream, Ikire, Southwestern Nigeria

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Introduction

Rivers play a vital role in rural communities, particularly for the fishing industry, for agricultural purposes and as a source of water for local people.^{1,2} River contamination affects humans directly and indirectly. However, increasing anthropogenic activities and natural processes decrease the quality of water and pose a threat to all forms of life. Poultry farms provide one of the leading sources of high-grade, protein-rich foods (eggs and meat) globally, however, domestic, industrial and agricultural poultry wastes are regularly discarded into water bodies.³

According to Okonkwo *et al.*, about 10 percent of the Nigerian population is engaged in poultry production, mostly at subsistence levels or on small and medium-sized farms.⁴ The increased

Background. Water supplies can be contaminated by anthropogenic activities. The poultry industry uses a variety of heavy metals as additives in chicken feed, but excretion, runoff and dumping of heavy metals can threaten water bodies and have adverse effects on human health. **Objectives.** The aim of the present study was to determine the environmental impact of heavy metals from poultry waste discharged into the Olosuru stream, located in Ikire, southwest Nigeria.

Methods. In order to study changes in heavy metal loads, samples were collected six times during the wet season (September, October 2014 and April 2015) and dry season (November 2014, January and February 2015). The inhabitants of Olosuru village use water for domestic and agriculture purposes from the Olosuru stream which is located only a few meters from a poultry farm discharge point. Three stations were sampled, upstream to downstream, with 500 meter distance between each point.

Results. Selected heavy metals concentrations in the Olosuru stream were all above the World Health Organization (WHO) standard for drinking water. The highest mean concentrations of heavy metals were recorded at the downstream station, while arsenic, iron and lead showed significant spatial and seasonal differences. Seasonally, the highest iron concentrations were recorded in the dry season (0.104 ± 0.401 mg/L), while the mean concentrations of other heavy metals recorded during the sampling period were higher during the wet season.

Conclusions. Concentrations of heavy metals in the present study were above acceptable limits. Poultry waste discharged into the Olosuru stream, can have negative impacts on the stream and health implications for local residents.

Competing Interests. The authors declare no competing financial interests.

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use of trace elements as nutritional supplements in poultry diets to improve feed efficiency, facilitate weight increase and for disease prevention results in high levels of trace elements in poultry waste.^{5,6} Many metals are added to poultry feed, including copper (Cu), manganese (Mn), iron (Fe), selenium (Se), zinc (Zn), and arsenic (As). Iron and Cu are added to prevent anemia, selenium is added to prevent oxidative damage to cells, and Zn and Mn are added to ensure

proper egg shell deposition and feather development. Antioxidants are added to retard degradation of vitamins in feed. Tranquilizers may be used to keep flocks quiet in the house and before transport. A broad spectrum of antibiotics may be added to poultry feed, both to combat pests and to increase availability of certain nutrients. Topical pesticides are used to combat flies, lice, beetles and mice.⁷ Unfortunately, contaminants from poultry farms can have adverse effects

on air, soil and water quality if their wastes are improperly managed and disposed of into the environment.⁸ The improper disposal of wastes generated by poultry operations has been a long-standing concern due to the contribution to nutrient pollution in water resources.⁹ Poultry wastes can degrade water quality when they are channeled directly into surface water or enter water bodies via surface runoff. The main environmental and health risks associated with animal wastes are the introduction of pollutants such as nutrients (including nitrogen and phosphorous), organic matter, sediments, pathogens (including bacteria and viruses) and heavy metals.¹⁰ The danger lies in accumulation of manure-borne metals, since they are not biodegradable and eventually become phytotoxic.¹¹ Long-term application of poultry waste on soil has also been shown to result in accumulation of trace elements, increasing the potential bioavailability and toxicity of metals in the environment.¹²⁻¹⁵ Such accumulation has the potential of restricting soil function, contaminating the food chain and water, and causing toxicity to plants, animals, water and humans.^{16,17} Poultry waste is more toxic than other animal wastes.¹⁸ Land application of poultry manure may result in the uptake of toxicants by plants, animals and humans through absorption, ingestion, bioaccumulation or other processes. Following the introduction of heavy metal contaminants into a river, whether via natural or anthropogenic sources, they partition between aqueous (pore water and overlying water) and solid phases (sediment, suspended particulate matter and biota).^{19,20} Although some heavy metals are required as micronutrients, they can be toxic when present in higher amounts than their requirements. Anthropogenic metals may consistently persist within water bodies or maybe taken up by

| Abbreviations | |
|---|--------------------------|
| CV | Coefficient of variation |
| <p>organisms such as plankton, benthos or fish and finally transferred to humans.²¹ As heavy metals cannot be degraded, they are deposited, assimilated or incorporated in water, sediment and aquatic animals, thus causing heavy metal pollution in water bodies.²² Lead is a toxic metal that is particularly harmful to children.²³ Lead affects the central and peripheral nervous system, organs, bones and kidneys.²⁴ Lead has no beneficial biological function and is known to accumulate in the body.²⁵⁻²⁷ Lead exposure can cause adverse health effects, especially in young children and pregnant women, since Pb is a neurotoxin that permanently interrupts normal brain development. It also accumulates in the skeleton and its mobilization from bones during pregnancy and lactation causes exposure to fetuses and breastfed infants.^{28,29} Lead on a cellular and molecular level may increase carcinogenic events involved in DNA damage and suppress DNA repairs and regulation of tumors.³⁰</p> <p>A number of studies have been carried out on heavy metal concentrations in animal feeds and manure. Hill <i>et al.</i> carried out an experiment on the impact of animal waste application on runoff water quality in field experimental plots and concluded that a major concern of using animal waste as a source of fertilizer is the potential of degrading any nearby natural water sources.³¹ Zhang <i>et al.</i> studied the heavy metal content of poultry waste collected from several farms in north-east China, with concentrations ranging from 2.88-98.08 mg/kg, 0.02-6.42 mg/kg and non-detectable-8.00 mg/kg for</p> <p>Cu, As and cadmium (Cd) respectively. Their results indicate that some animals can build up heavy metals through their feed.³² Islam <i>et al.</i> found that the various sources of raw materials used for poultry feed production are likely associated with anthropogenic heavy metal pollution. They also reported mean concentrations of heavy metals in some poultry feeds sold in Bangladesh ranging from 0.1852-0.0232 ppm for Cd, 20.6498-0.6019 ppm for lead (Pb), 0.7640-0.0069 ppm for As, 0.0579-0.0116 ppm for mercury (Hg), 0.0347-0.0069 ppm for Se, 5.7875-0.0926 ppm for chromium (Cr), 302.2001-0.0695 ppm for Mn, 5.1625-0.0125 ppm for nickel 37.5725-0.0463 ppm for Cu and 422.3023-0.0232 ppm for Zn.³³</p> <p>The present study of the Olosuru stream is important, as residents of Olosuru village obtain water for domestic purposes from the stream only a few meters upstream from a poultry farm discharge point. Additionally, agricultural products, including vegetables and banana are cultivated along the path of the stream after the point of discharge. Thus, the aim of the present study was to assess the environmental stress and potential harm in relation to heavy metal concentrations that can result from improper discharge of untreated poultry wastes on the water quality of Olosuru stream at Ikire, southwest Nigeria.</p> | |
| <h3>Methods</h3> <p>This present study was carried out on a stretch of the Olosuru stream (latitudes 07°20' N -07°22'N; Longitude 004°10'E</p> | |

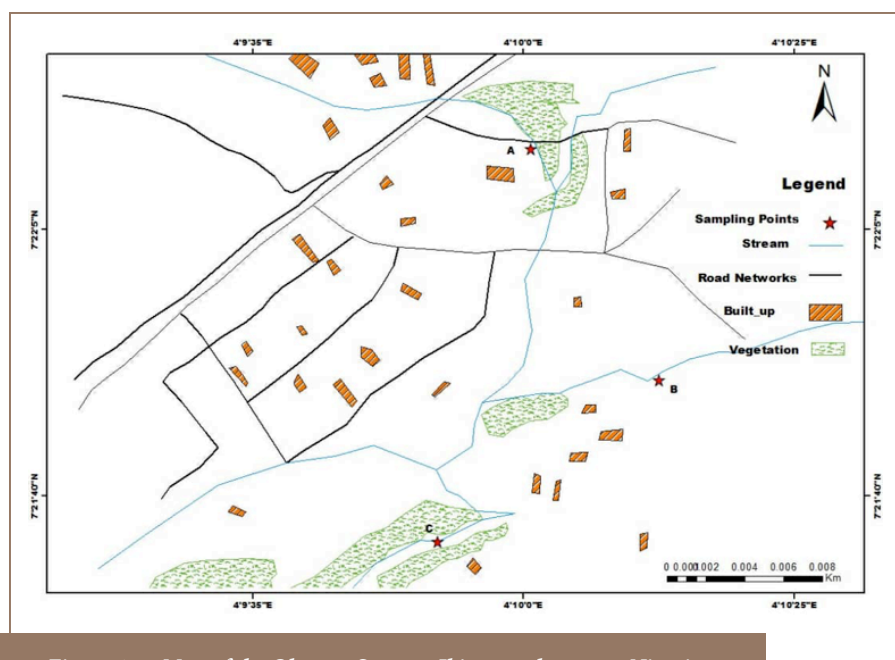


Figure 1 — Map of the Olosuru Stream, Ikire, southwestern Nigeria

- 004°11'E), which is a tributary of the Asejire River, southern Nigeria (Figure 1). The Olosuru stream drains into Asejire River at Ikire, Osun State. The headquarters of Irewole Local Government area of Osun State is located in the Ikire urban area. The Local Government Area shares boundaries with Ayedire to the north, to the south with Isokan, to the east with Ayedaade, and to the south east by Ife-North Local Government Areas of Osun state respectively. It also bounds with Egbeda Local Government Area of Oyo state to the west. Ikire Urban area has a land mass of approximately 270 km². According to the 2006 census by the National Population Council, Ikire had an estimated population of about 144,000.³⁴ The climate of the area is humid and tropical with a mean annual temperature of about 27°C and a mean annual rainfall of over 1,400 mm. A geology survey map indicates that the basement complex in this area are migmatized, gneisses and granite. There are occurrences

of schist and quartzite, occasionally amphibolite, gabbro, diorites; the dominant in the studied area is gneisses.^{35,36} The soils are primarily well-drained, Apomuseries soils known as cambicarenosols.³⁷ The study area falls within the rainforest belt of Nigeria, with a wet season (April to October) and a dry season (November to March).

Sampling stations and collection

Three sampling stations were established along the stream namely: upstream (A), the discharge point (B) and downstream (C). The upstream station was located about 500 meters away from the discharge point at Olosuru community. Human activities here include mechanical workshops, car washes and occasional road side oil spillage. The discharge point was located where poultry waste is directly discharged into the stream. The downstream sampling point is about 500 meters from the discharge point. This station was established to

determine the recovery ability of the stream from the discharge point. The downstream station has the highest level of human activities/disturbance, including bathing, swimming, local fishing and washing of clothes and household utensils.

Water samples were collected six times, from the rainy season (September, October 2014 and April 2015) through the dry season (November 2014, January and February 2015) to study changes in heavy metal loads. Water samples were collected in 2-litre double-capped polyethylene bottles prewashed with detergent diluted with nitric acid and double distilled deionized water. In the field, sampling bottles and covers were rinsed three times with sampling water prior to sampling. Samples were acidified with 1% nitric acid to prevent heavy metals from adhering to the wall of the sampling bottle and were subsequently stored at 4°C for a minimal period of time, before analysis, to minimize changes in the physico-chemical characteristics of the metals.

Heavy metal analysis

For each sampling station, a 50 ml water sample was measured into a 250 ml conical flask and digested with 10 ml nitric acid. The samples were heated on a hot plate to a reduced volume of 5-7 ml. Digested samples were filtered using Whatman No.4 filter paper and deionized water was added to increase the volume to 100 ml. A blank was also prepared as a control.³⁸ The determination of heavy metals in each sample was carried out using an atomic absorption spectrophotometer (PG-990 model) calibrated with the standard for each metal under investigation at individual wavelengths of 248.3, 283.3, 228.8, 279.4 and 119.3 nm for Fe, Pb, Cd, Mn and As, respectively.

Results

Cadmium was significantly positively correlated with As, Mn and Pb at $p < 0.01$ and with Fe at $p < 0.05$. Arsenic, Fe and Mn were significantly positively correlated with Pb at $p < 0.05$. Lead had a positive significantly correlation with Mn at $p < 0.01$ (Table 1).

Principal component analysis of heavy metals

Principal component analysis was established to identify the distribution of metals within the sampling areas. The first two components for the wet season accounted for 99.93% of the cumulative variation. The first component accounted for 96.99% of the explained variance. Iron and Mn recorded high positive loadings of 6.55 and 0.19, respectively. The second component accounted for 2.94% of the explained variance. Only Mn recorded high positive loadings of 1.18.

The first two components for the dry season accounted for 99.92% of the total variation. The first component accounted for 97.56% of the explained variance. Iron and Mn recorded high loadings of 6.56 and 0.24, respectively. The second component accounted for 2.36% of the explained variance. Manganese recorded high positive loadings of 1.06.

The first component of the explained variance for the upstream, discharge

and downstream accounted for 98.55%, 98.0% and 95.72%, respectively. Iron and Mn recorded high positive loadings of 5.96 and 0.003 (upstream), 4.14 and 0.20 (discharged point) and 5.78 and 0.34 (downstream), respectively (Table 2).

Figure 2 presents a histogram diagram of monthly variation patterns for selected heavy metals during the sampling period. Cadmium concentrations during the study

| | Cd | As | Fe | Mn | Pb |
|----|----------------------|----------------------|----------------------|----------------------|----|
| Cd | 0 | | | | |
| As | 0.47507 ^b | 0 | | | |
| Fe | 0.39792 ^a | 0.16234 | 0 | | |
| Mn | 0.47717 ^b | 0.19845 | 0.15184 | 0 | |
| Pb | 0.51387 ^b | 0.24683 ^a | 0.30569 ^a | 0.59847 ^b | 0 |

^a Significant difference ($p < 0.05$)

^b Highly significant difference ($p < 0.01$)

Table 1 — Correlation Coefficient of Heavy Metals Measured at the Olosuru Stream, Ikire, Southwestern Nigeria

| Principal component | Spatial variation | | | | | | Seasonal variation | | | |
|---------------------|-------------------|----------|-----------------|----------|------------|----------|--------------------|----------|------------|----------|
| | Upstream | | Discharge point | | Downstream | | Dry season | | Wet season | |
| | UPCA1 | UPCA2 | DPPCA1 | DPPCA2 | DSPCA1 | DSPCA2 | DPCA1 | DPCA2 | WPCA1 | WPCA2 |
| Eigenvalue | 11.8292 | 0.161331 | 5.88062 | 0.115172 | 11.4859 | 0.502324 | 14.6343 | 0.353385 | 14.5484 | 0.441587 |
| % variance | 98.576 | 1.3444 | 98.01 | 1.9195 | 95.716 | 4.186 | 97.562 | 2.3559 | 96.989 | 2.9439 |
| Cumulative | 98.58 | 99.92 | 98.01 | 99.93 | 95.72 | 99.91 | 97.56 | 99.92 | 96.99 | 99.93 |
| Cd | -1.9751 | -0.1155 | -1.4046 | -0.14066 | -2.0179 | -0.34998 | -2.2123 | -0.23169 | -2.2458 | -0.32582 |
| As | -2.0838 | -0.22176 | -1.5026 | -0.17202 | -2.1058 | -0.35139 | -2.292 | -0.30842 | -2.4045 | -0.33687 |
| Fe | 5.9552 | -0.17954 | 4.144 | -0.17929 | 5.7759 | -0.38403 | 6.5625 | -0.30102 | 6.5532 | -0.33073 |
| Mn | 0.003367 | 0.71504 | 0.20436 | 0.60525 | 0.33826 | 1.2592 | 0.23683 | 1.061 | 0.19177 | 1.1837 |
| Pb | -1.8996 | -0.19824 | -1.4412 | -0.11328 | -1.9904 | -0.17382 | -2.2951 | -0.2199 | -2.0946 | -0.19027 |

Abbreviations: UPCA, upstream principal component analysis; DPPCA, discharge point principal component analysis; DSPCA, downstream principal component analysis; DPCA, dry season principal component analysis; WPCA, wet season principal component analysis.

Table 2 — Principal Component Analysis for Spatial and Seasonal Variation of Heavy Metals Concentrations in the Olosuru Stream, Ikire Southwestern Nigeria

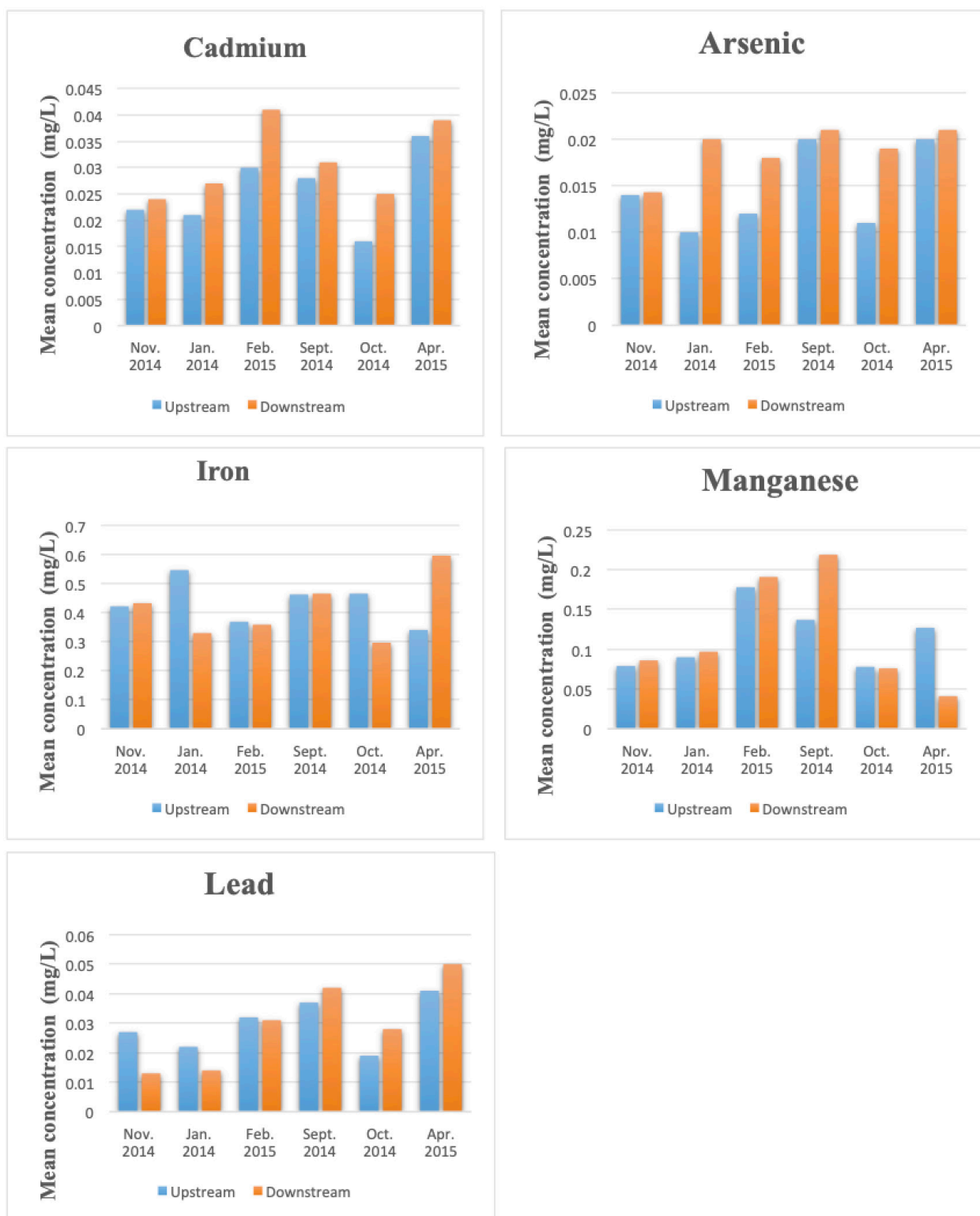


Figure 2 — Histogram diagram of monthly variation of heavy metals in the Olosuru stream, Ikire, southwestern Nigeria

period peaked in February 2015 at the downstream station and in April 2015 at the upstream station. The lowest Cd concentration occurred at the downstream station in November 2014 and the upstream station in October 2014. The highest As concentration was observed in September 2014 and April 2015 for both the upstream and downstream stations. The lowest As concentration was observed in November 2014 for the downstream station and in January 2014 for the upstream station.

The highest peak for Fe occurred in April 2015 and lowest was recorded in October 2014 for the downstream station, and for the upstream station the highest was observed in January 2014 and the lowest in April 2015. The highest Mn concentration was recorded in September 2014, while the lowest occurred in April 2015 for the downstream location. The upstream Mn concentration was highest in February 2015, while the lowest occurred in October 2014. The highest Pb concentration was recorded in April 2015 for both the downstream and upstream stations, while the lowest was recorded in November 2014 for the downstream station and October 2014 for the upstream station.

Figure 3 depicts a cluster diagram illustrating the relationship between heavy metals in the Olosuru stream. At $p < 0.05$ Mn, Pb and Cd form a clustering with As and Fe, while at $p < 0.01$, Mn, Pb and Cd form another cluster, and at $p < 0.001$ only Mn and Pb form a cluster diagram.

Generally, all of the selected heavy metals analyzed in the present study increased in concentration toward the downstream station, as shown in Table 3. The Cd concentration varied widely from 0.006 to 0.032 mg/L (0.015 ± 0.001 mg/L) and the highest mean value was at the downstream station

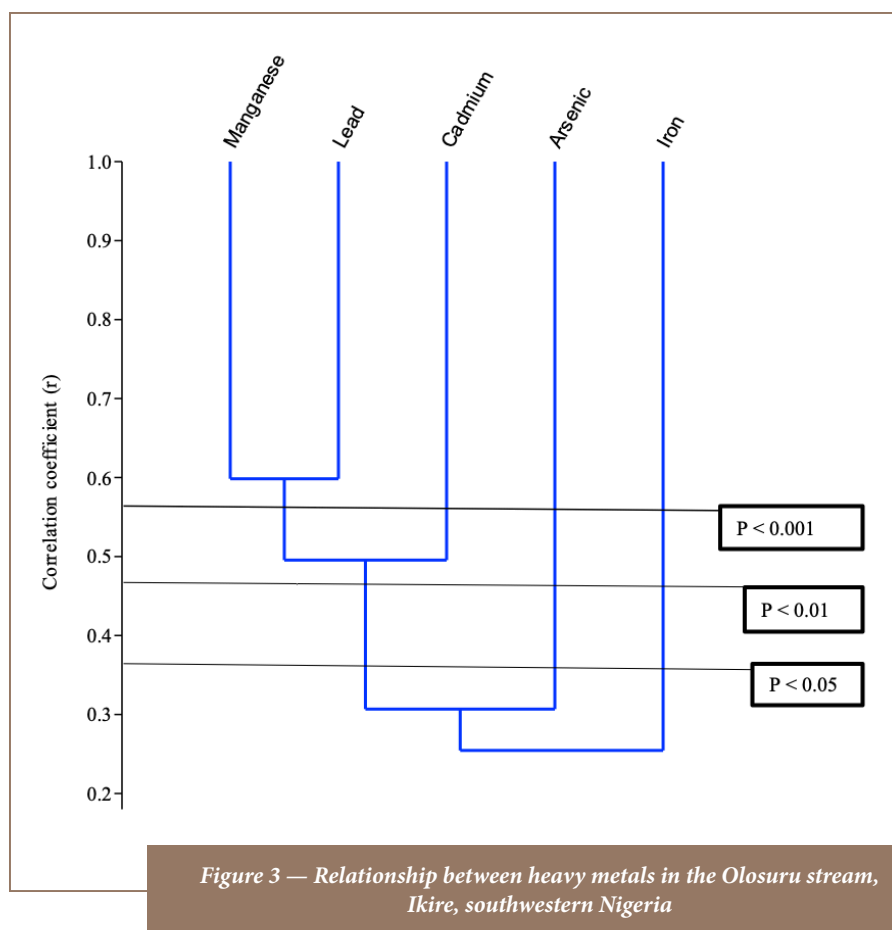


Figure 3 — Relationship between heavy metals in the Olosuru stream, Ikire, southwestern Nigeria

(0.018 ± 0.002 mg/L). Concentrations of Pb ranged from 0.007 to 0.120 mg/L (0.021 ± 0.001 mg/L), while the highest mean concentration was observed at the downstream station (0.031 ± 0.013 mg/L). The Mn level in the water samples varied widely from 0.035 to 0.243 mg/L and had a mean concentration of 0.064 ± 0.012 mg/L, with the highest mean value recorded at the downstream station (0.0192 ± 0.021 mg/L). Iron concentrations ranged from 0.085–0.410 mg/L, with an overall mean value of 0.210 ± 0.010 mg/L, while the highest mean value was observed at the downstream location (0.260 ± 0.021 mg/L) with significant differences ($p < 0.05$) in spatial variation. Concentrations of As recorded during

the sampling period ranged from 0.007 to 0.023 mg/L with a mean value of 0.016 ± 0.002 mg/L, and the highest mean concentration was observed at the downstream location (0.045 ± 0.031) (Table 3).

The highest Cd concentration was recorded during the wet season (0.006–0.032 mg/L) and there was a significantly higher concentration recorded during the wet season (0.016 ± 0.003 mg/L) compared to the dry season (0.015 ± 0.001 mg/L) (Table 4). The highest mean of Pb concentration occurred during the wet season (0.021 ± 0.008 mg/L) compared to dry season (0.017 ± 0.002 mg/L). The difference was highly significant

| Parameter | Spatial variation | | | | | | | | | |
|-----------|-------------------|-------------|-----------------|-------------|-------------|-------------|-------|--------------------|-------------|-------------|
| | Upstream | | Discharge point | | Downstream | | Anova | | Overall | |
| | Min-max. | Mean±sem | Min-max. | Mean±sem | Min-max. | Mean±sem | F | P | Min-max. | Mean±sem |
| Cd | 0.006-0.026 | 0.015±0.002 | 0.006-0.026 | 0.016±0.003 | 0.011-0.032 | 0.018±0.002 | 0.025 | 0.975 | 0.006-0.032 | 0.015±0.001 |
| As | 0.008-0.016 | 0.012±0.001 | 0.007-0.019 | 0.014±0.002 | 0.011-0.023 | 0.045±0.031 | 4.608 | 0.012 ^a | 0.007-0.023 | 0.016±0.002 |
| Fe | 0.104-0.274 | 0.203±0.013 | 0.085-0.296 | 0.212±0.029 | 0.122-0.410 | 0.260±0.021 | 3.116 | 0.024 ^a | 0.085-0.410 | 0.210±0.010 |
| Mn | 0.036-0.101 | 0.065±0.006 | 0.035-0.113 | 0.069±0.014 | 0.038-0.243 | 0.192±0.021 | 1.249 | 0.302 | 0.035-0.243 | 0.064±0.012 |
| Pb | 0.008-0.025 | 0.015±0.001 | 0.007-0.024 | 0.014±0.002 | 0.011-0.120 | 0.031±0.013 | 2.19 | 0.013 ^a | 0.007-0.120 | 0.021±0.001 |

Abbreviation: sem, standard error of mean.

^a Significant different (p<0.05)

Table 3 — Spatial Variation of Heavy Metals in the Olosuru Stream, Ikire, Southwestern Nigeria

| Parameter | Dry season | | Wet season | | Anova | |
|-----------|-------------|-------------|-------------|-------------|-------|--------------------|
| | Min-max. | Mean±sem | Min-max. | Mean±sem | F | P |
| Cd | 0.006-0.019 | 0.015±0.001 | 0.006-0.032 | 0.016±0.003 | 0.001 | 0.967 |
| As | 0.008-0.019 | 0.013±0.001 | 0.007-0.023 | 0.031±0.020 | 2.105 | 0.032 ^a |
| Fe | 0.104-0.410 | 0.217±0.016 | 0.085-0.274 | 0.220±0.012 | 0.026 | 0.869 |
| Mn | 0.035-0.113 | 0.064±0.007 | 0.038-0.243 | 0.085±0.013 | 1.838 | 0.186 |
| Pb | 0.008-0.027 | 0.017±0.002 | 0.007-0.120 | 0.021±0.008 | 5.284 | 0.001 ^b |

Abbreviation: sem, standard error of mean

^a Significant difference (p<0.05)

^b Highly significant difference (p<0.01)

Table 4 — Temporal Variation of Heavy Metals in the Olosuru Stream, Ikire, Southwestern Nigeria

| Parameter | Spatial variation | | | Seasonal variation | | Overall |
|-----------|-------------------|-----------------|------------|--------------------|------------|----------|
| | Upstream | Discharge point | Downstream | Dry season | Wet season | |
| | CV (%) | CV (%) | CV (%) | CV (%) | CV (%) | |
| Cd | 39.5358 | 34.49638 | 39.18681 | 30.4412 | 46.51677 | 36.3966 |
| As | 39.8767 | 46.36809 | 36.88639 | 27.8428 | 27.86472 | 38.63177 |
| Fe | 27.4136 | 34.72949 | 26.42321 | 41.4317 | 42.66579 | 27.11495 |
| Mn | 32.78687 | 47.40117 | 44.81874 | 42.5609 | 32.11165 | 45.48953 |
| Pb | 23.62908 | 59.80524 | 49.46856 | 30.5511 | 25.75373 | 29.86993 |

Abbreviation: CV, coefficient of variation.

Table 5 — Coefficient of Variation (%) of Heavy Metals Measured in the Olosuru Stream, Ikire, Southwestern Nigeria

(p<0.01). The mean concentration of Mn was higher during the wet season (0.085±0.013 mg/L) than the dry season (0.064±0.007 mg/L). Iron had a mean concentration of 0.220±0.012 during the wet season and 0.217±0.016 during the dry season. The highest mean concentration of As was recorded during the wet season (0.031±0.020 mg/L) and had a mean concentration of 0.013±0.001 mg/L during the dry season.

The overall coefficient of variation (CV) for Cd was low (36.39%). However, a higher CV of Cd was recorded at the upstream station (39.54%) and during the wet season (46.52%). The overall CV recorded for Pb was also low (29.86%) compared with the CV recorded at the discharge point (59.81%). The CV of Pb recorded during the dry season (30.55%) was higher than the wet season (25.75%). The overall CV for Mn was high (45.49%), while the highest CV was recorded at the discharge station (47.40%) and the CV recorded during the wet season (42.56%) was higher than the dry season (32.11%). The overall CV recorded for Fe during the study period was low (27.11%), while a high CV was recorded at the discharge station (34.73%) and the CV recorded during the wet season (42.66%) was

higher than the dry season (41.43%). The overall CV recorded for As during the study period was low (38.63%), and the highest recorded CV occurred at the discharge point (46.37%) (Table 5).

Discussion

The Cd concentrations recorded in the water samples collected from all the sampling stations across all seasons were above the United States Environmental Protection Agency (USEPA) permissible limit of 0.005 mg/L for drinking water.³⁹ The monthly mean concentrations were higher at the downstream station compared to the upstream station. The highest mean concentration of Cd was recorded at the downstream station during the wet season. The high Cd concentrations in the present study could be due to bioaccumulation and subsequent discharges of poultry waste into the stream at the discharge point. The results obtained in the present study are similar to a report by Alexieva *et al.*, which found elevated concentrations of Cd in poultry and pig feed and manure in Bulgaria.⁴⁰ Heavy metals were also found to be retained in animal flesh and in some of their waste, indicating that significant concentrations of heavy metals in animal feed and waste can pose a threat to human health through water, soil and plant contamination.⁴⁰ These results align with those of a study by Taiwo and Arowolo which reported Cd mean concentrations from not detected to 0.07 mg/L in stream water in Abeokuta, Nigeria.⁴¹ The high Cd levels recorded in the present study could be because of an excess of the element excreted in chicken fecal waste and urine.^{42,43} The significant positive correlation of Cd with other heavy metals indicates that as concentrations of Cd increase, others do as well. High concentrations of Cd in water can lead to cancer and affect hormones and enzymes, which can lead to malformations, including renal

damage.^{43,44}

The peak Pb concentration was recorded in April 2014, and the mean concentrations of Pb recorded at all sampling stations were higher than the World Health Organization (WHO) permissible standards (0.01 mg/L) for drinking water.⁴⁵ These high concentrations could be a result of excess Pb from food additives excreted in waste. These results are similar to those in a study by Richard *et al.*, which reported a correlation between the concentrations of Pb in poultry feed and waste.⁴⁶ However, this potential can be altered at elevated concentrations, as lead ions may diffuse into body systems. High Pb concentrations pose an inherent danger to nearby villages along the path of the Olosuru stream.

The mean recorded values for Mn across all stations were greater than the 0.05 mg/L recommended limits for drinking water.⁴⁵ Mean Mn concentrations were higher at the downstream station compared to the upstream station except for April 2015. Manganese is used in the poultry industry to prevent deficiencies and disease, improve weight gain and feed conversion and increase egg production. These practices can result in elevated concentrations in manure byproducts.^{41,47-52} Excess Mn negatively affects brain development, behavior, learning ability and memory. The tolerable upper intake levels for humans are 2 mg for those 1-3 years of age, 3 mg between 4-8 years of age, 6 mg between 9-13 years of age, 9 mg between 14-18 years of age and 11 mg for those 19 years and older. Manganese is required as a catalytic cofactor for mitochondrial superoxidized is mutase, arginase, and pyruvate carboxylase. It is also an activator of glycosyltransferases, phosphoenol pyruvate carboxylase, and glutamine synthetase. Symptoms of Mn deficiency include impaired growth, skeletal abnormalities and defects in

lipid and carbohydrate metabolism. Iron-manganese interactions have been demonstrated whereby Fe deficiency increases Mn absorption, and high amounts of dietary Fe inhibit Mn absorption, possibly by competition for similar binding and absorption sites between nonheme Fe and Mn.⁵³ The mean Fe concentrations recorded during the sampling period were lower than the recommended value by the WHO (0.3 mg/L) for domestic use.⁵⁴ Iron is the fourth most abundant element by mass in the earth's crust. In water, it occurs mainly in ferrous or ferric states.⁵⁵ Iron in surface water is generally present in the ferric state. It is an essential and non-conservative trace element found in significant concentrations in drinking water because of its abundance in the earth's crust. Usually, Fe in groundwater is in the form of ferric hydroxide, in concentrations less than 500 µg/L.⁵⁶ A shortage of Fe causes anemia and prolonged consumption of drinking water with high concentration of Fe may lead to haemosiderosis.^{57,58} There is no guideline set by the National Environmental Standards and Regulations Enforcement Agency Federal Environmental Protection Agency (NESREA) for Fe content in drinking water, as it is not a health concern at concentrations normally observed in drinking water.⁵⁹

The mean As concentration observed in the present study was above the WHO (0.01 mg/L) recommended standard limits for drinking water. The highest mean value of As was observed at the downstream station, where there was a high level of human activity. The increase in As concentration in the present study could be due to the addition of As in poultry feed as an additive to control coccidiosis in chickens, which has resulted in a seven-fold increase in As levels in poultry waste.⁶⁰ It is now recognized that at least 140 million people in 50

countries have been drinking water containing arsenic at levels above the WHO provisional guideline value of 10 µg/L.⁶¹ Arsenic occurs in two forms, organic As and inorganic As. Inorganic As compounds (such as those found in water) are highly toxic, while organic As compounds (such as those found in seafood) are less harmful to human health. Acute effects of As in water could lead to immediate symptoms such as vomiting, abdominal pain and diarrhea, while long-term effects can be observed in the skin and include pigmentation changes, skin lesions and hard patches on the palms and soles of the feet (hyperkeratosis). The International Agency for Research on Cancer has classified As and As compounds as carcinogenic to humans and has stated that As in drinking water is a carcinogen.⁶²

Conclusions

The heavy metals contents of the Olosuru stream in the present study were above acceptable limits for drinking water. The study also showed evidence of water pollution across all sampling stations, indicating that the water is not safe for consumption except when treated.

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